Spatial and Temporal Variability of Carbon Dioxide: A Local-to-Global Perspective.

AIRS
AQUA
TCCON
NOAA

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NASA LEARN Program

The NASA LEARN Project is an innovative program that provides educators with on-site research and training with NASA scientists during the summer and guided research projects that continue on throughout the school year. These educators conduct their own research, with help of a team of NASA scientists, through on-site collaboration and virtual meetings. They share and integrate these projects into the classroom, concluding the process by presenting their projects at a final poster session attended by the NASA Langley Science Directorate.

Background

Carbon dioxide, a naturally-occurring trace gas comprising about 0.039% of Earth's atmosphere, has gained considerable attention in recent decades for its ability to store thermal (IR) energy, contributing to the phenomenon called the Greenhouse Effect. This compound, combined with the effects of water vapor, methane, CFCs, and ozone, among others, alter Earth's radiation budget to produce higher global temperatures, local weather extremes, and changes to planetary ecology.

With historical evidence supporting atmospheric CO_2 concentrations of no more than 300 parts per million volume (ppmv) in the last 800,000 years, an increase of 100 ppmv since the onset of the Industrial Revolution is statistically significant. Despite its importance in photosynthesis, its molecular stability, combined with the use of fossil fuels, changes in land use, and population growth contribute to increased atmospheric concentrations and ocean acidification.

From an academic perspective, understanding the temporal and spatial variability of carbon dioxide will provide valuable insight into how the carbon cycle works on micro and macro scales. By examining data recorded from ground stations and satellite systems, correlations can be made that can validate their readings and show how carbon dioxide moves through the atmosphere over time, as well as showing differences in concentrations in different parts of the atmosphere.

Data Sources

A variety of data were used to not only gain perspective in *how* carbon dioxide values are recorded, but also to shed light on the differences in readings that result from *where* the measurements are taken:

	AIRS (AQUA)	TCCON	NOAA
Program Description	Atmospheric Infrared Sounder; on NASA AQUA satellite. While *not optimized for CO_2 measurement*, delivers mid-tropospheric (5-9 km)readings with a scan swath of about 800 km. Covers entire planet each day.	Total Carbon Column Observing Network; a series of 18 ground-based Fourier Transform Spectrometers operated in a variety of locations. Can record several readings per minute. Used to measure the accuracy of measurements taken by SCIAMACHY .	NOAA's CO_2 measurement program, conducted near the summit of Mauna Loa (3400m asl), provides the longest continuous data on atmospheric carbon dioxide in the world. It was begun by C. D. Keeling at the Scripps Inst. of Oceanography in 1958.
Instrumentation	IR spectrometer using 2378 channels; 90 footprints per 2.667-second scan period (using a rotary scan mirror providing up to 49.5° of coverage) at an altitude of about 700 km.	A Fourier Transform Infrared Spectrometer uses IR light to measure gases contained in the air through which the light passes. The term Fourier refers to the formula used to convert time data into a frequency function.	Fourier Transform Infrared Spectrometer ; hourly calibration using reference gases of known CO_2 mole fraction.
Accuracy	Up to 4 parts per million volume (ppmv), when compared to flask measurements taken in the mid-troposphere.	Approximately 1 ppmv; achieved by comparisons to aircraft flask measurements over each site.	Continuous calibration (hourly) provides for an accuracy of 0.2 ppmv. Accuracy determined by flask samples analyzed off-site .
Limitations	Does not take readings below 60° south latitude. Data retrievals occur every 16 days; however, data product is a monthly average over a broad geographic area (each data point represents 2°x2.5° area).	No readings taken during cloudy (or worse) conditions. Many sites are remote; with equipment malfunctions, significant gaps in data can exist.	Values represent "air masses that are representative of very large areas"; values for a single site and elevation.
Data Lifetime	Sep 2002-Present	Varies by site; earliest recorded data May 2004-Present.	May 1974-Present; additional supporting data to 1958.

Hardware

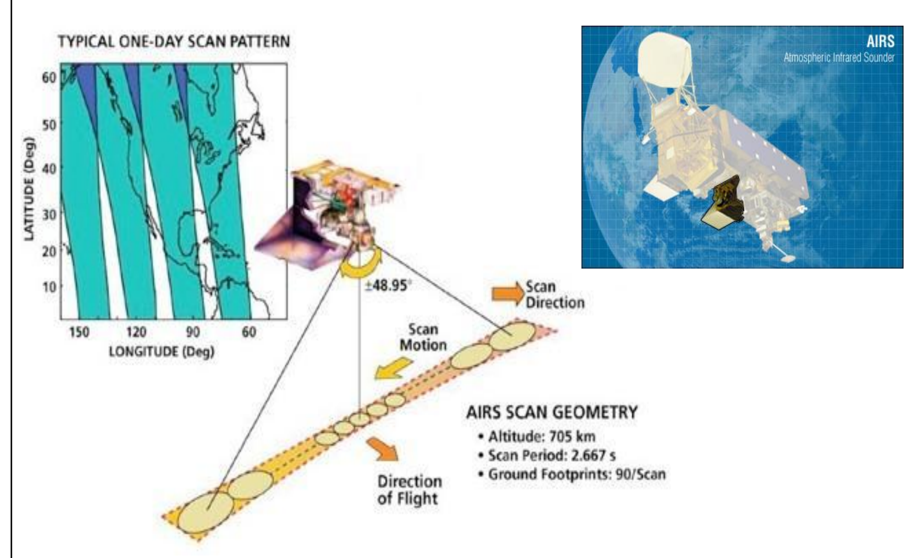


Figure 7: AIRS instrument structure and function. Note that AIRS is one component of the AQUA satellite, containing several different instruments.

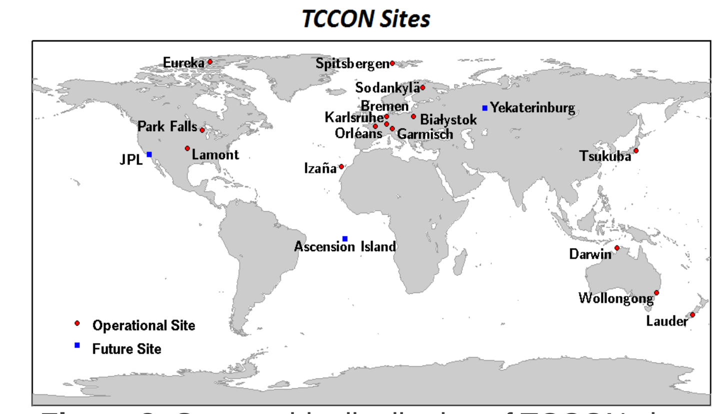


Figure 8: Geographic distribution of TCCON sites.

Figure 9: Mauna Loa Observatory; NOAA.

Figure 10: Darwin, Australia TCCON site.

Procedure

One of the take-home concepts of NASA LEARN is the availability of NASA datasets for classroom and amateur scientific use. In this case, AIRS and TCCON CO_2 data were utilized. In addition, CO_2 concentration data from the Mauna Loa Observatory were compared with previously-collected data..

Because AIRS, TCCON, and NOAA data were formatted differently, it was important to translate them into a usable form that could be read, analyzed, and graphed with a minimum of difficulty; to wit, Microsoft Excel was used as a repository for these datasets.

With AIRS data, a text-to-columns arrangement delineated by latitude and longitude requires sorting. NOAA's data is similarly organized. On the other hand, TCCON data is organized to accommodate the vast number of readings that are taken by each site's system; at last count, per available data, the Darwin station has logged more than 159,000 CO_2 readings, even with notable gaps . Data of this system is delineated by day-of-year as well as decimal UTC time, with an added caveat of negative values. This is done because many TCCON stations operate in time zones where a local day crosses over two UTC dates. The UTC day value that comes first is used, hence the need for negative values to describe readings that occur around a change to a new day.

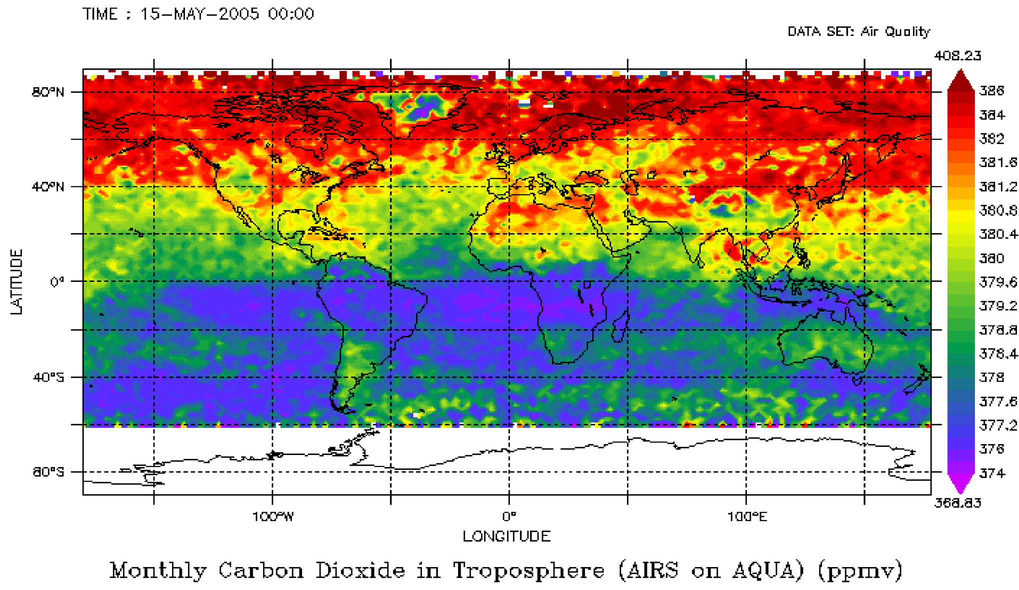
The decision was made to use data values for the years 2005-2011 because this provided full years' worth of data from each resource (AIRS 9/2002-present; TCCON 9/2005-present; NOAA 3/1958-present). However, due to data processing timeframes, not all data is available immediately (current AIRS availability 2/2012; TCCON 6/2012; NOAA 5/2013).

Data were graphed for ease of viewing similarities in the datasets, determining if data were correlated, and if there were explainable differences in the data between different modalities in a particular timeframe. Data were graphed using the Igor software program.

Correlations were conducted by plotting datasets with identical date ranges; a slope value of 1 (one) was favorable to conclude the datasets have a positive relationship.

The creation of line graphs to display CO_2 data is ideal because potential change over time is being measured, and each timeframe used in graphing is not necessarily a different and distinct category to be compared. MYNASADATA's graphical interface allows the user to create full-color and time-series graphics of its datasets; these were instrumental in the first steps of data analysis for this project.

Figure 1: Monthly averages of CO_2 concentrations; AIRS (AQUA); May, 2005.



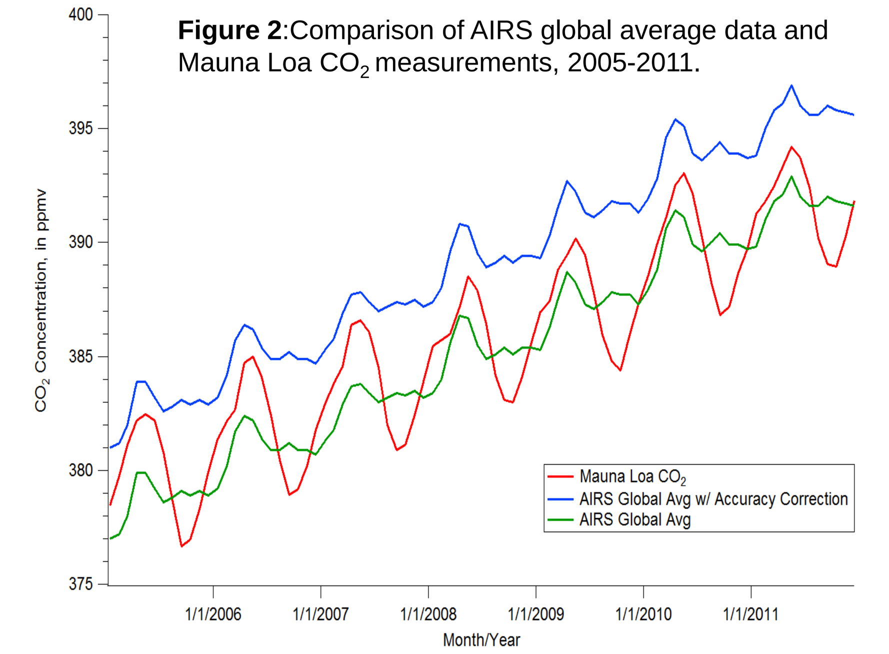


Figure 2:Comparison of AIRS global average data and Mauna Loa CO_2 measurements, 2005-2011.

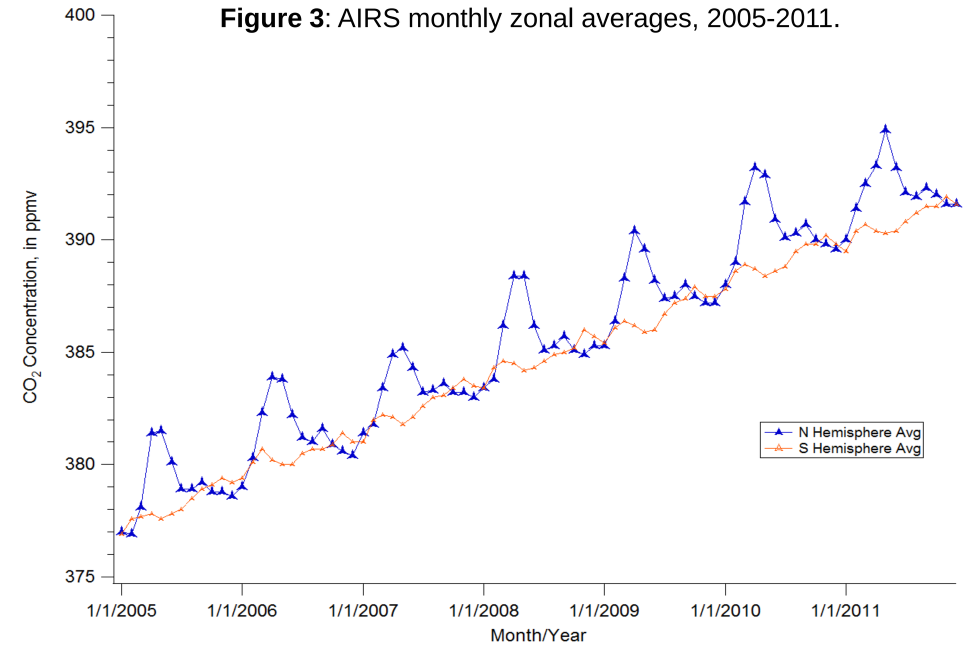


Figure 3: AIRS monthly zonal averages, 2005-2011.

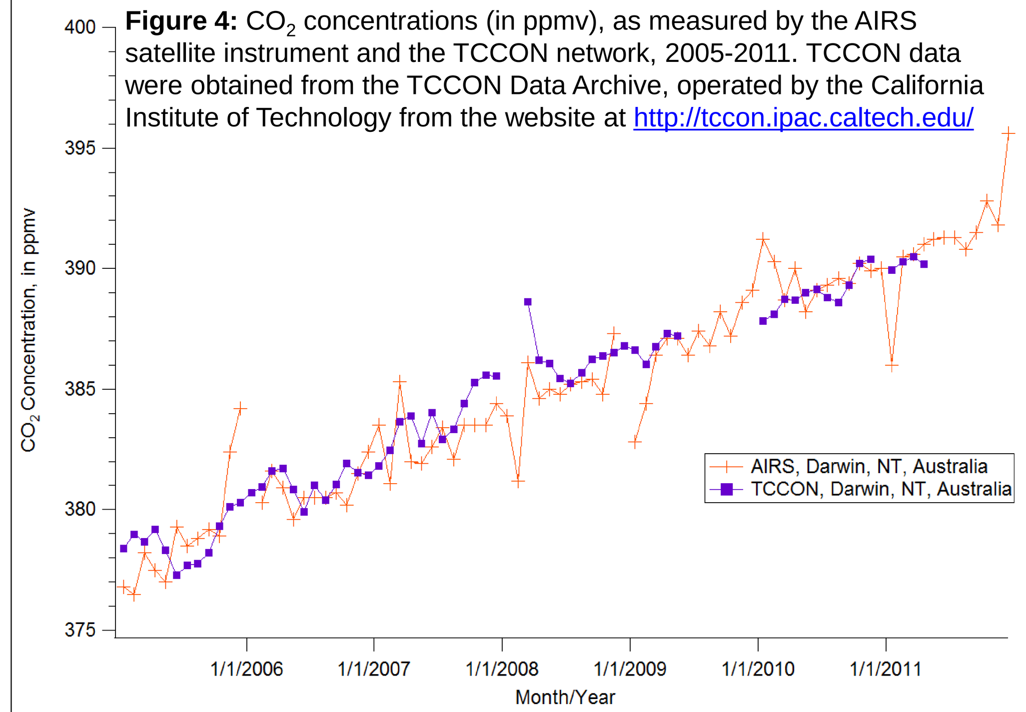


Figure 4: CO_2 concentrations (in ppmv), as measured by the AIRS satellite instrument and the TCCON network, 2005-2011. TCCON data were obtained from the TCCON Data Archive, operated by the California Institute of Technology from the website at http://tccon.ipac.caltech.edu/

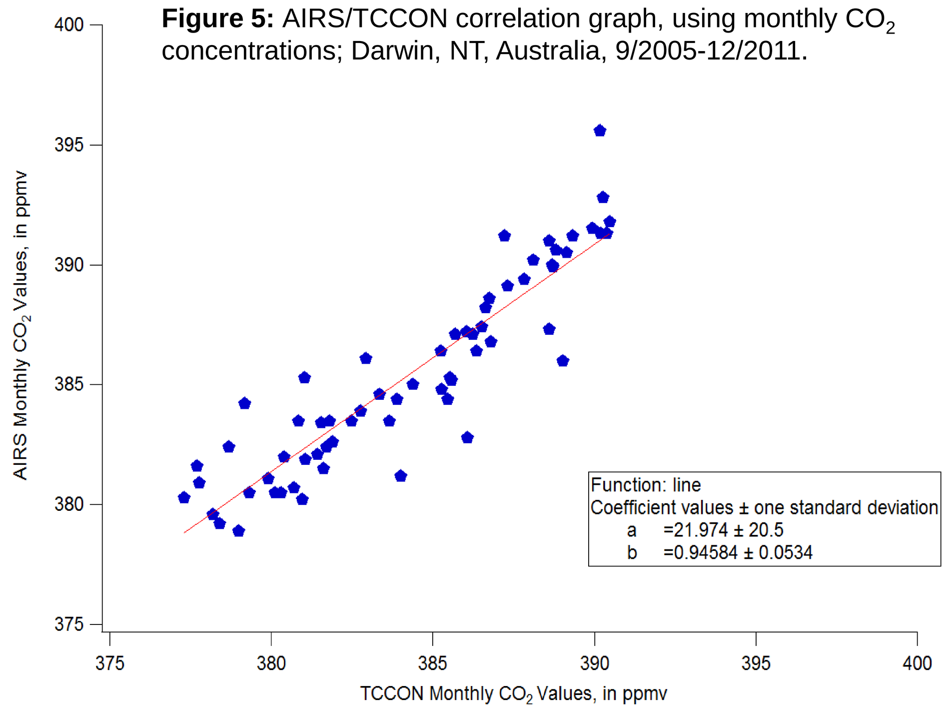


Figure 5: AIRS/TCCON correlation graph, using monthly CO_2 concentrations; Darwin, NT, Australia, 9/2005-12/2011.

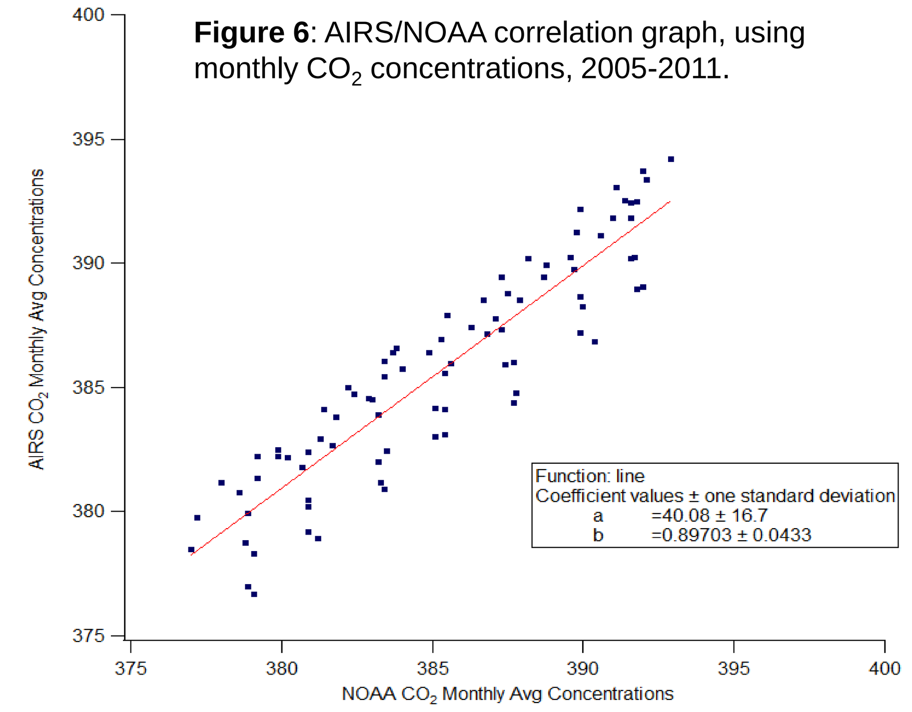


Figure 6: AIRS/NOAA correlation graph, using monthly CO_2 concentrations, 2005-2011.

Student Interaction

While not directly involved in data analysis and research, sixth grade mathematics enrichment students from John Yeates Middle School had the opportunity to study AIRS, TCCON, and NOAA data in tabular and graphical forms. Groups of students were given a data sample and asked to generate questions and conclusions based on the data, as well as comments regarding the data's format, ease of use, and relevant math concepts. This process was repeated four times during the session.

Many students had initial difficulty reading data, attributed mainly to map keys and/or to length of datasets. This underlies the need for teachers to periodically revisit graph interpretation and analysis, regardless of its presence or absence in state mathematics standards.

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Results

1. Does CO_2 vary temporally? Yes.

Factors such as plant life cycles, ocean uptake, and air/water currents are but a few reasons why CO_2 varies temporally. While Figure 1 displays a "snapshot" of carbon dioxide concentrations in one month, Figures 2, 3, and 4 show conclusively its variability.

2. Does CO_2 vary spatially? Yes.

Carbon dioxide varies according to zone, altitude, and location, according to the site's characteristics. Figure 3, generated by northern and southern hemisphere means (AIRS), reflects the demographic differences between these hemispheres; there are more people in the North, hence more industrial activity, fossil fuel consumption, and a balance of unused CO_2 by the increased flora.

In addition, the differences exhibited by the AIRS instrument and the TCCON system (Figure 4) show spatial variability. By design, AIRS takes measurements in the mid-troposphere (5-9 km asl), while TCCON readings are drawn from samples in the low troposphere (0-5 km asl). It must be noted as well that these layers markedly differ in their stability, with low-troposphere being the region from which Earth weather precipitates.

Similarly, the data gathered at NOAA's Mauna Loa Observatory, while taken at a higher altitude (3.4km asl), show the same seasonal variability that the AIRS instrument collects, though their methods and volume of data differ (Figure 2, 6).

3. Does the data support temporal and spatial variability? Yes!

The data are well-correlated, evidenced by Figures 5 and 6. The descriptions of each measuring system display distinct differences, and the data are slightly different as well. However, the correlation graphs also display positive slopes of 0.95 and 0.9, respectively, denoting a strong correlation between the two datasets compared (values <0 show negative correlation; values >0 show positive correlation). In short, the data collected, by their different processes and locations, are showing the same upward trend indicative of the steady increases in CO_2 that have been observed since the onset of the Industrial Revolution.

Next Steps

Knowing that different CO_2 –measurement systems/data correlate well to each other, and that CO_2 varies spatially and temporally, the next question that begs asking relates to public perception, action planning, and environmental stewardship: what is the best way to communicate CO_2 data to the public? Is there a formula that can account for low- and mid-tropospheric CO_2 data and zonal differences to produce a sensible values to enhance public knowledge and effect change in human practices?